MESOSPHERIC RETRIEVALS FROM MIPAS

Luis F. Millán-Valle and A. Dudhia

Oxford University, Parks Road Oxford OX1 3PU, U.K., e-mail: millanvalle@atm.ox.ac.uk

ABSTRACT

A linear algorithm has been developed to retrieve temperature, pressure and composition at lower mesospheric altitudes using the limb radiances from the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). The algorithm is based on the assumption that at mesospheric heights, due to the thin optical path, the retrieval can be treated linearly. This avoids re-running the radiative transfer model and hence avoids the high CPU cost. A comparison against the operational level 2 (L2) products is given.

Key words: Mesosphere; MIPAS; retrieval.

1. INTRODUCTION

Recently, physical processes in the mesosphere have attracted the attention of the science community. Understanding of these processes requires measurements of the mesospheric temperature and gas concentrations, but unfortunately, few instruments are capable of sounding this region.

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) is an infrared Fourier transform interferometer on board the Envisat satellite launched on March 1, 2002. It covers the mid infrared spectral region between 4.1 - 14.6 μm (2410 - 685 cm^{-1}) in five spectral bands, which contains emission lines of many atmospheric species [1]. Normally MIPAS scans from 6 to 68 km but its altitude coverage can be extended to tangent altitudes above 100 km under special viewing modes: the middle atmosphere mode covering the altitudes from 18 to 102 km in 29 steps and the upper atmosphere mode covering the altitudes from 42 to 172 km in 35 steps, both of them capturing the entire mesosphere. Currently, every ten days the middle atmosphere mode is used. This implies that 10% of the viewing time will be expendeded in the mesosphere.

The operational L2 retrievals use an iterative microwindow approach which implies re-running the radiative transfer model [2]. Microwindows are small subsets of the complete MIPAS spectrum which represent regions of the spectrum with maximum information content of the target molecule and minimum contribution from systematic errors [3]. When trying to extend that type of retrieval into the mesosphere, the low signal to noise (S/N) ratio requires many more spectral points to be used and hence much longer processing time. The reason for the low S/N ratio is that in the mesosphere the atmospheric paths become optically thin. That fact may allow retrieving the temperature, pressure and composition using a linear (non iterative) retrieval covering the entire emission bands of the molecule rather than isolated microwindows. This paper describes a linear retrieval scheme used for the inversion of MIPAS CO_2 limb radiances into temperature and pressure at lower mesospheric altitudes followed by the retrieval of Ozone and Water vapour volume mixing ratio.

2. PRESSURE-TEMPERATURE RETRIEVAL

The pressure-temperature (pT) retrieval starts with the L1B data (the geolocated and calibrated spectra) from the spectral range 685-970 cm^{-1}. The fist step is to identify mesospheric emission lines of gases other than CO_2 as well as CO_2 lines affected by non Local Thermal Equilibrium (nonLTE) processes to be masked out of the measurements. This is done to avoid errors due to interfering lines of other molecules or errors due to a difference between the local kinetic temperature and the Planck temperature of the radiation field. To do this, reference spectra from common mesospheric species for the heights to be retrieved were precomputed with the Reference Forward Model (RFM), as well as CO_2 lines with and without nonLTE effects. The RFM is a line-by-line radiative transfer model developed at Oxford University and is the radiative transfer model used in this retrieval.[1]

Fig. 1 summarises these processes. The top panel displays the average spectra measured for 07 June 2003 at 52 km. Each colour represents a different gas or CO_2 lines affected by non LTE processes. The bottom panel shows the remaining CO_2 after the masking process.

After that, temperature and pressure are retrieved by a linear least squares fit of the form,

$$\mathbf{x} = \mathbf{x}_o + (\mathbf{K}^T\mathbf{K})^{-1}\mathbf{K}^T(\mathbf{y} - f(\mathbf{x}_o)) \qquad (1)$$

where $\mathbf{x}$ is the state vector which includes all the parameters to be retrieved, $\mathbf{y}$ is the measurement vector containing limb radiances, $f(\mathbf{x}_o)$ is the precomputed reference spectra (the result of the radiative transfer model f using the initial guess atmosphere $\mathbf{x}_o$), and K is the Jacobian (or weighting function) matrix with elements,

[1] Documentation of it can be found at http://www.atm.ox.ac.uk/RFM

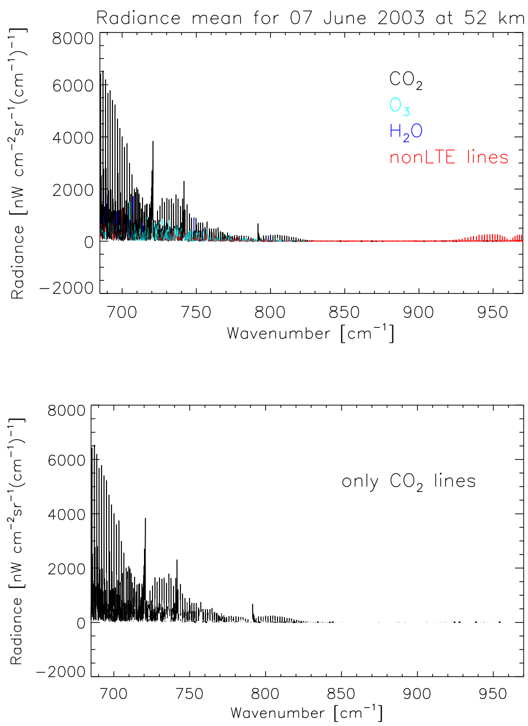

Figure 1. MIPAS average radiance for 07 June 2003 and CO_2 lines remaining after the masking process.

$K_{ij} = \delta y_i / \delta x_j$ precomputed for the initial guess atmosphere $\mathbf{x}_o$.
Even though the main goal is the retrieval of atmospheric temperature, it has been found that the linearity of retrieval improves if Planck function is retrieved rather than temperature. Ignoring the effect of the finite field of view and assuming that all the emission is at the tangent point, the radiance may be written as,

$$R = a\frac{pv}{T}B(T) \tag{2}$$

where R is the radiance, B is the Planck function, and the rest is the emissivity of the path (p is pressure, T is temperature, v is volume mixing ratio and a is a constant). As can be seen, $\delta R/\delta T$ (the temperature Jacobian) is a function that includes the derivative of the Planck function (proportional to T^c where c is greater than 1), while $\delta R/\delta B$ is only a function of the pressure, the concentration and the temperature, and hence, more linear. Therefore, Planck function is the quantity retrieved and once the retrieval is complete, the retrieved Planck function is converted into temperature.
Three different initial guesses are used to improve the retrieval accuracy, corresponding to mid latitude, polar summer and polar winter conditions. In the three cases, the retrieval scheme is carried out and the one that most closely predicts the observed spectra is used.

2.1. Hydrostatic balance constraint

Assuming that the atmosphere is in hydrostatic balance, the engineering altitude measured at each scan provides an additional piece of information. This can be used to constrain the temperature and pressure via the hydrostatic equation,

$$z_{i+1} - z_i = \Delta z = \frac{R}{g}\overline{T}\log\left(\frac{p_i}{p_{i+1}}\right) \tag{3}$$

where, z's are the corresponding engineering altitudes, R is the gas constant for dry air (287 JK^{-1} kg^{-1}), g is the acceleration due to gravity (assumed to be constant), p's are the pressures for those heights and $\overline{T}$ is the averaged temperature of the layer (assumed to vary linearly with height), $\overline{T} = (T_i + T_{i+1})/2$. This constraint is added using the standard optimal estimation approach described by [4],

$$\mathbf{x}_h = \mathbf{x} + (\mathbf{K}_h^T\mathbf{S}_h^{-1}\mathbf{K}_h + \mathbf{S})^{-1}\mathbf{K}_h^T\mathbf{S}_h \\ [(\mathbf{y} - f(\mathbf{x}_o) - \mathbf{K}_h(\mathbf{x} - \mathbf{x}_o))] \tag{4}$$

where $\mathbf{x}_h$ is the optimal solution to x (the state vector just retrieved), $\mathbf{S}_h$ and $\mathbf{S}$ are the covariance matrices for the difference in the engineering altitude and the temperature and pressure retrieved (described in the next section), and $\mathbf{K}_h$ is a Jacobian given by,

$$\frac{\delta\Delta z}{\delta T_i} = \frac{\delta\Delta z}{T_{i+1}} = \frac{R}{2g}\left(\log\left(\frac{p_i}{p_{i+1}}\right)\right) \\ \frac{\delta\Delta z}{\delta\log p_i} = -\frac{\delta\Delta z}{\log p_{i+1}} = \frac{R}{g}\overline{T} \tag{5}$$

The same scheme is used by the operational L2 retrieval described by [2].

2.2. Retrieval random errors

The random retrieval error is given by the covariance matrix,

$$\mathbf{S}_e = (\mathbf{K}_h^T\mathbf{S}_h^{-1}\mathbf{K}_h + \mathbf{S}^{-1})^{-1} \tag{6}$$

where $\mathbf{S}_h$ is covariance matrix of the difference in the engineering altitude (where the standard deviation of it has been considered to be 100 m), and $\mathbf{S}_a$ is the retrieval error associated with the temperature and pressure retrieval given by,

$$\mathbf{S} = (\mathbf{K}^T\mathbf{S}_n^{-1}\mathbf{K})^{-1} \tag{7}$$

where $\mathbf{S}_n$ is the covariance matrix of the noise for the spectral range used.

3. RESULTS AND COMPARISON TO OPERATIONAL L2 PRODUCT

The top panel of fig. 2 top panel displays the zonal average temperature retrieved from the lower mesospheric

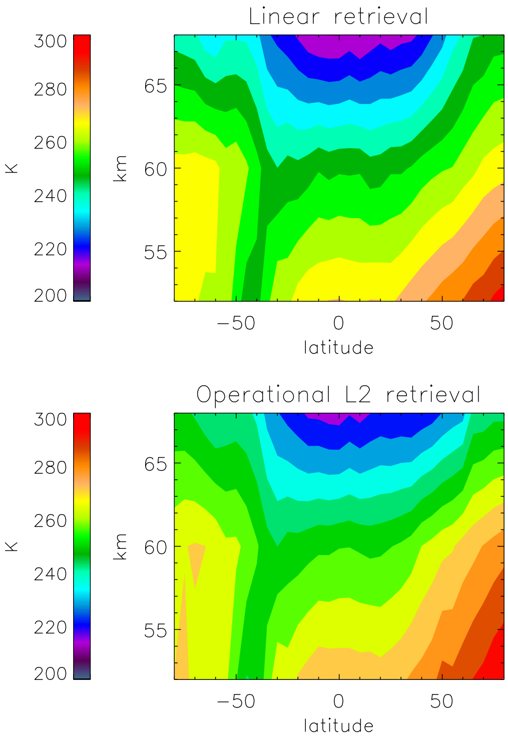

Figure 2. Zonal average of the temperature retrieved with the linear scheme and the operational L2 retrieval for 07 June 2003.

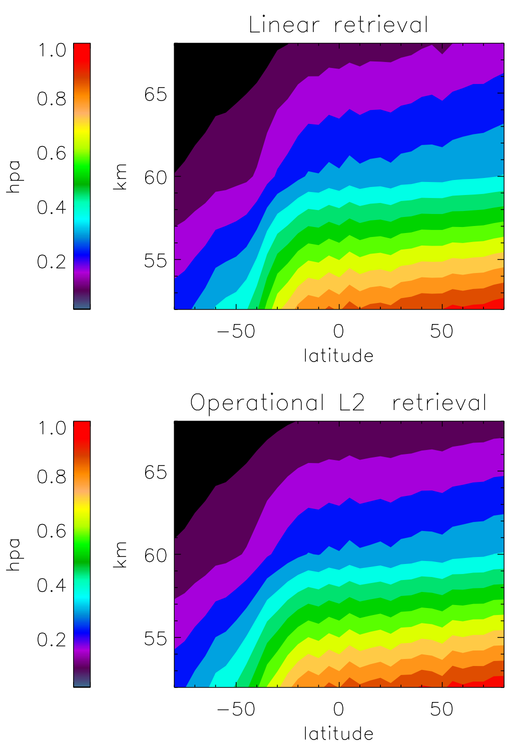

Figure 3. Zonal average of pressure retrieved with the linear scheme and the operational L2 retrieval for 07 June 2003.

radiances on 7 June 2003 with the algorithm introduced here while the bottom panel shows the standard L2 operational product. Fig. 3 shows the zonal average pressure retrieved with the linear algorithm and from the operational L2 data. In both cases, the retrieval is generally consistent with the operational L2 products.
To be able to compare both retrievals a χ^2 test was used,

$$\chi^2 = \frac{(x_{L2} - x_h)^2}{\sigma_{L2}^2 + \sigma_e^2} \tag{8}$$

where x_{L2} corresponds to the L2 operational product (temperature or pressure), x_h the correspondent linear retrieval value, σ_{L2} the error of the L2 retrieval and σ_e is the error of the linear retrieval (the standard deviation derived from the square root of the diagonal elements of the covariance matrix, S_e).The temperature presents a χ^2 value of 3.36 while the pressure of 5.46
It is important to highlight the fact that the errors of the linear retrieval are smaller than the errors of the operational L2 product. For these altitudes the average temperature error for the operational L2 product is 1.40 K while the average error for the linear retrieval is 0.77 K. The average pressure error for the operational L2 products is 0.0043 hPa while for the linear retrieval is 0.0035 hPa.

4. RETRIEVAL OF GAS CONCENTRATIONS

Once the temperature and pressure have been retrieved, the same type of linear approach can be used to retrieve gas concentrations. First, a spectral range is chosen where most lines of the molecule to be retrieved are located. As previously described, interfering emissions from other molecules and non-LTE effects are screened out. Then, assuming the radiance measured is given by,

$$\mathbf{y} = \mathbf{y}_o + \frac{\delta R}{\delta B}(\mathbf{B} - \mathbf{B}_o) + \frac{\delta R}{\delta p}(\mathbf{p} - \mathbf{p}_o) + \frac{\delta R}{\delta v}(\mathbf{v} - \mathbf{v}_o) \tag{9}$$

where $\mathbf{B}$ is the corresponding Planck function (at a fixed wavenumber) for the actual temperature, $\mathbf{p}$ is the actual pressure (these last two having been retrieved previously), $\mathbf{B}_o$ is the Planck function (at the same fixed wavenumber) for the temperature value of the initial guess, $\mathbf{p}_o$ and $\mathbf{v}_o$ correspond to the pressure and concentration values of the initial guess, and $\delta R/\delta B$, $\delta R/\delta p$ and $\delta R/\delta v$ are the Planck function, pressure and volume mixing ratio Jacobians ($\mathbf{K}_B$, $\mathbf{K}_p$, $\mathbf{K}_v$, respectively); the concentration can be retrieved as follows,

$$\mathbf{v} = \mathbf{v}_o + (\mathbf{K}_v^T \mathbf{K}_v)^{-1} \mathbf{K}_v^T \left[\mathbf{y} - \mathbf{y}_o - \mathbf{K}_B(\mathbf{B} - \mathbf{B}_o) - \mathbf{K}_p(\mathbf{p} - \mathbf{p}_o)\right] \tag{10}$$

Until now, only O_3 and H_2O have been retrieved but more species will be retrieved. The spectral range used to retrieve ozone is 1020 - 1170 cm^{-1}, while for H_2O it is

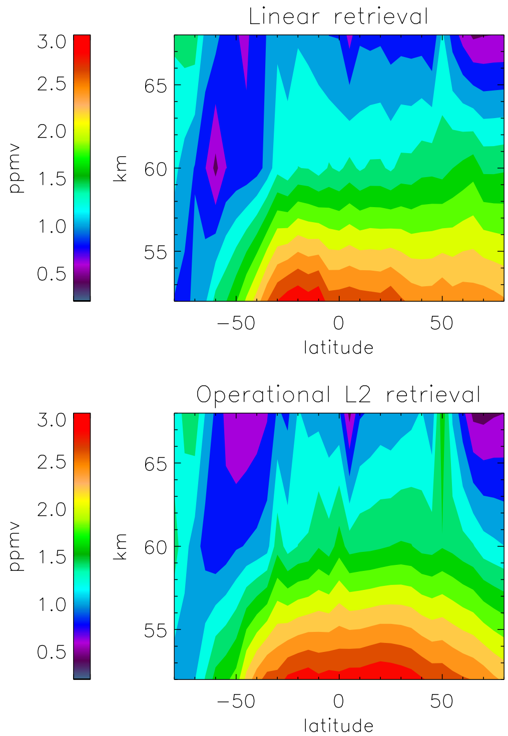

Figure 4. Zonal average ozone retrieved with the linear scheme and the operational L2 retrieval for 07 June 2003.

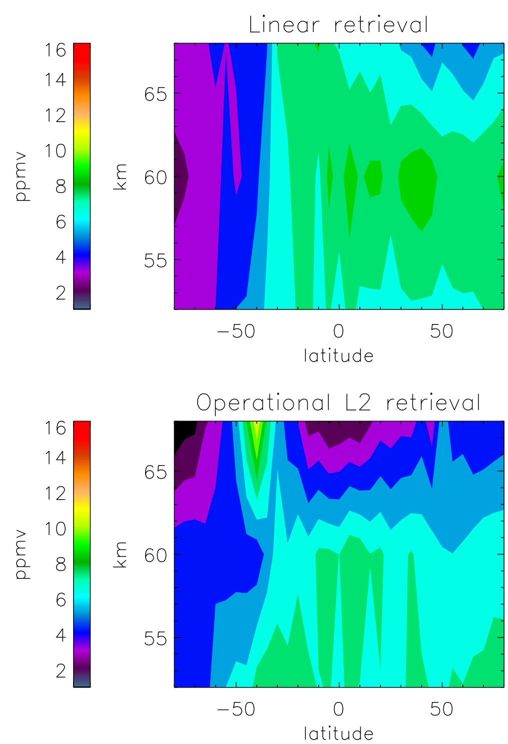

Figure 5. Zonal average water vapour retrieved with the linear scheme and the operational L2 retrieval for 07 June 2003.

1215-1500 cm^{-1} The top panel of fig. 4 shows the O_3 retrieved with the linear retrieval while the bottom panel shows the operational L2 product. Fig. 5 displays the same but for water vapour. As can be seen, systematic differences appear in this retrieval.

To compare the O_3 retrievals, the χ^2 test described previously, was used. In this case, x_{L2} corresponds to the volume mixing ratio of the L2 operational product, x_h corresponds to the concentration just retrieved, and σ_e is the square root of the diagonal elements of the covariance matrix,

$$\mathbf{S}_v = (\mathbf{K}_v^T \mathbf{S}_n^{-1} \mathbf{K}_v)^{-1} \qquad (11)$$

The O_3 retrieval produces a χ^2 of 5.77

Due to the differences between the water vapour retrievals, no test to compare them was used.

5. SUMMARY AND CONCLUSIONS

An alternative algorithm to retrieve temperature, pressure and concentrations at lower mesospheric altitudes from MIPAS limb radiances have been introduced. This algorithm exploits the linear properties of an optically thin path making it possible to perform the retrieval without re-running the radiative transfer model (allowing much wider spectral ranges to be used). The main advantage is the saving in CPU cost in comparison with those of the operational L2 MIPAS algorithm. A concluding remark is that linearity is gained by retrieving Planck function rather than temperature. The retrieval will be extended to higher altitudes and more gases will be retrieved with the same approach: using the whole signature of the molecule rather than just microwindows.

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